"Task-Managed" Watchstanding: Providing Decision Support for Multi-Task Naval Operations

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ABSTRACT
Watchstanding in shipboard command centers requires U.S. Navy crews to complete time-critical and externally paced task assignments in an accurate and timely manner. Requirements for optimized crew sizes in future ships are driving system designers toward human–computer interface designs that mitigate task and workload demands in a multi-task work environment. The multi-task mission is characterized by multiple concurrent task demands and parallel task goals of varying time duration. Design concepts for a multi-modal watchstation work environment were created that support a variety of crew cognitive and visual requirements during these high-demand missions. Key user support tools include a concept of embedded "task management" within the watchstation software. Early tests of "task-managed watchstanding" have yielded promising results with regard to performance, situation awareness, and workload reduction. Design concepts are now being transitioned into newer naval systems under SSC San Diego guidance and direction.

INTRODUCTION

Crew size and function allocation in future ships have been recognized as a significant cost factor and therefore have become a performance capability objective for a new class of ships planned for later in this decade [1]. Human performance, driven by a complex, multi-task littoral mission job environment, is the rate-limiting factor for crew optimization. Total task workload must be distributed among a trained crew and controlled in a manner that allows successful performance with minimum risk of mission failure or compromise. Current design practice calls for systematic assignment of tasks (workload) to crew members in a fairly rigid manner—creating periods of high workload or overload for some crew members while others may sit nearly idle with low workload. Crew-size optimization calls for much higher precision in task assignments and workload optimization, with minimum waste in workload capacity as tasks are assigned to the smaller crew.

In 1996, the Multi-Modal Watchstation (MMWS) project was initiated to investigate design concepts that would support crew optimization in command centers. An ergonomic, task-centered watchstation was developed (see Figure 1). The design approach first identified user requirements related to the total work environment and task workload drivers. For purposes of this design discussion, we define a "task" as a job activity with the following attributes:

1. A goal-oriented work activity that results in a defined product.
2. Varying in time from seconds to hours, or the entire watch period (6 hours or more).
3. Supportable by computer-based aids (i.e., not physical work or maintenance activities, although such tasks could benefit by using the principles of this design).
4. Supportable by various levels of automation, which are, in some cases, user-selectable and, in others, may be fixed. Thus, levels of task supervision and user/system task sharing are dynamic.
5. May vary from structured, rigid protocols to open-ended, user-defined sequences. Following Rasmussen's hierarchy [2], tasks may include skill-, rule-, or knowledge-based behaviors.

An important aspect of the task-centric approach is the focus on the "total" work environment, which is defined as mission + computer interface + work management tasks. Naval system designers typically focus on the narrow "mission-specific" requirements to derive the specifications of software functional design. They neglect workload derived from human–computer interface task activities such as computer interface control (e.g., graphical user-interface manipulations). Also neglected is the considerable cognitive workload for work planning, task selection, and time or resource management. The human operator must constantly strategize and allocate attention resources across multiple concurrent events. Current designs offer little or no user assistance to reduce this type of workload or to foster efficiency. The MMWS design focus on task management issues led to a definition of estimated task characteristics for a future naval system, such as listed in Table 1 [4]. (See [3] for discussion of the Task Characteristics approach.) These characteristics provided a starting point for watchstation design concepts based on these requirements. Since task requirements were only available at an abstract level for the future ship [5] and no concept of operations existed at this early design phase, several important assumptions were made about the future task environment such as (1) what degree of automation would be available; (2) multitasking would be required for crew optimization across multiple threats and multiple warfare areas: land attack, air defense, and area air defense; (3) cross-training across multiple tasks would be possible; and (4) system design would permit assignment of any task to any crew member at a watchstation, limited only by authority and planned operating procedures. These task and design requirements were then used as a basis to generate preliminary design concepts.

FIGURE 1. Ergonomic Multi-Modal Watchstation Pedestal. The MMWS console was designed to accommodate the 2.5% female through 97.5% male reach envelopes.

PRELIMINARY DESIGN

Each of the concept design requirements was matched with a variety of user-interface aids to support each task type. The design process employed was similar to that noted by Neerincx [6] in which tasks were defined according to their impact on cognitive performance. Specifically, tasks were good candidates for automation support that were judged to be skill- or rule-based. The allocation of task responsibility was considered to be dynamic and user controllable for most tasks. Certain mission tasks better fit the procedural aspects of skill-based behavior (e.g., when the air threat assessment process is completed and the procedural mechanics of issuing warnings or countermeasures become a primary task goal). Design concepts were created to address these projected requirements (Table 1), and examples are listed in Table 2.

The design concept of an "Information Set" was created to contain the "default" or typical information needed to support a task operator. The goal of the design approach was to automate much of the information-seeking task steps. An effective information set would filter pertinent information for the specific task from the visual "noise" or unimportant data. For example, a particular land-attack task in a given geographic sector would require the information set to filter the tactical display to show relevant threats and friendly forces icons. Information sets were defined to contain various graphical user-interface windows such as (1) tactical summary (situation awareness), communications (who to talk or listen to relevant to the task); (2) time and work management (task summary as shown in Figure 2); and (3) amplifying information specific to the task type (e.g., identification [ID] basis information for assessment when issuing a warning). Simple graphic-design rules were developed such as color-filled tactical symbol objects to represent tracks with a pending task and color-outlined symbols to represent no current work in progress.

To address requirements related to depiction of task progress, information formats related to task management were designed. Early concepts addressing air defense task progress were created in 1989 and reported in Osga [7]. Design concepts for the Response Planner Display from the Tactical Decision-Making Under Stress (TADMUS) project were also

TABLE 1. Key task characteristics related to task management requirements.

Task Characteristics Tasks:	**Design Requirement** System should:
May have definable start/stop schedules	Monitor concurrent loading and make schedules visible to user.
Have definable goals	Monitor progress toward goals—offer assistance if needed— report progress toward goals—allow user to modify or create new goals.
Are grouped as parts of overall job role	Provide visual indication of task assignments and task "health."
May be user and/or system invoked	Indicate who has task responsibility. Invoke and "offer" tasks when possible.
Have information and control requirements	Minimize workload to access information or controls.
Are mission- or computer-control focused	Provide full top-down task flow and status for mission tasks with consistent, short multi-modal procedures.
May involve varying levels of automation from full manual to partial to fully automated	Provide visual indication of automation state with supervisory indicators.
May require one or many databases	Do not require the user to know which database for any task. Direct queries automatically.
May require one or many software applications	Require user to know the tasks, not multiple applications—integrate information across the job vs. application.
Will require attention shift between multiple tasks in foreground and background (parallel)	Provide attention management and minimize workload to shift task focus.
Have definable cognitive, visual, and motor workload components	Use task estimates for workload distribution and monitoring among crew members.
Will likely be interrupted	Provide assistance to re-orient progress and resources to minimize working memory load.
Should be consistent from training to field	Provide consistent terms, content, and goals throughout.
Will evolve as missions, systems evolve over the life cycle of the ship	Support reconfiguration of task groupings and addition of new tasks as systems are upgraded.
May be individual or collaborative	Support close proximity and distant collaboration via visual and auditory tools.

TABLE 2. Key MMWS design concepts related to design requirements.

MMWS Design Concepts	**Design Requirement—**System should:
Response Planner/Manager—individual threat response summary. Task Manager Display—composite workload and tasks.	Monitor concurrent loading and make schedules visible to user.
Response Planner/Manager—range-based, single threat summary. Task Manager Display—task summary display.	Monitor progress toward goals—offer assistance if needed—report progress toward goals—allow user to modify or create new goals.
Task Manager Display—team overview and workload indicators.	Provide visual indication of task assignments and task "health."
Task Manager Display—task assignment summary. MMWS context and event monitoring to support task initiation.	Indicate who has task responsibility. Invoke and "offer" tasks when possible.
Multiple display surfaces—maximize visual workspace (within 5 to 95% reach envelope for touch).	Minimize workload to access information or controls.
Task manager task filters. Response Planner procedural list.	Provide full top-down task flow and status for mission tasks with consistent, short multi-modal procedures.
Visual coding of automtion state.	Provide visual indication of automation state with supervisory indicators.
Information sets automatically created.	Do not require the user to know which database for any task. Direct queries automatically.
"Information Sets" assigned to each task.	Require user to know the tasks, not multiple applications—integrate information across the job vs. application.
Multiple displays, task locator icons, intelligent task sorting and priority visual cues.	Provide attention management and minimize workload to shift between task focus.
Visual indication of team workload.	Use task estimates for workload distribution and monitoring among crew members.
Highlight changed information when task is "dormant." Reminders and notes tied to tasks.	Provide assistance to re-orient progress and resources to minimize working memory load.
Top-down task description carried through in display design as well as training curriculum.	Provide consistent terms, content, and goals throughout.
Design TBD	Support reconfiguration of task groupings and addition of new tasks as systems are upgraded.
3-D auditory support to spatialize multiple voice circuits, audio icons and visual/auditory linking of events (audio spatialized to match visual location.	Support close proximity and distant collaboration via visual and auditory tools.

reviewed [8 and 9]. The Response Planner display was used to depict planned response actions in air defense warfare showing task duration and dead-lines related to individual air threats. For MMWS, an additional response manager was added for electronic warfare tasks related to uncorrelated electronic-signature reports. Figure 3 (lower part) shows the MMWS "Response Planner/ Manager (RPM)" dis-play concept. This decision sup-port window depicts the major steps in the detect-to-engage

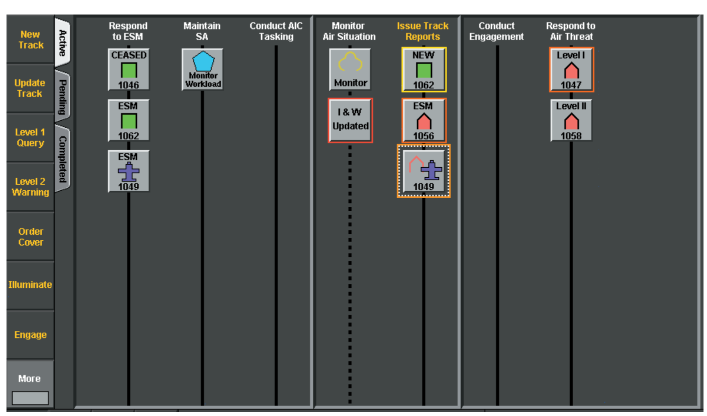

FIGURE 2. MMWS task management display with icons representing tasks awaiting user attention.

sequence that are possible and the ranges at which they might be completed and be in accordance with current response doctrine. Currently recommended task bars are filled white with an unfilled status circle. Previously completed tasks are represented by task bars that are filled black with a green status circle. Tasks that possibly could be triggered if the track maintains its current ID are gray with white letters. Tasks that will not be triggered if the track maintains its current ID are filled in with gray and with gray letters. The task bars are selectable, and the operator can launch a task manually by clicking on them. The RPM window is paired with the Track Profile Window, shown as the upper window in Figure 3. Both windows share a common range-scale from ownship. The track profile window provides a graphical representation of the hooked track's altitude and speed as a function of range from ownship. The altitude trail is color-coded to display the ID history of the track. The speed trail is shown in white. Commercial air transport (COMAIR) ranges are shown colored in purple along both the altitude and speed axis of the graph. Black boxes with white letters displayed along the altitude trail show the tasks performed for that track.

For air defense warfare, the following codes are used on the track profile to display which task was performed:

N = New Track Report issued
U = Update Track Report issued
Q = Level I Query issued
W = Level II Warning issued
V = Visual Identification (VID) ordered
C = Cover ordered
I = Illuminated
E = Engaged

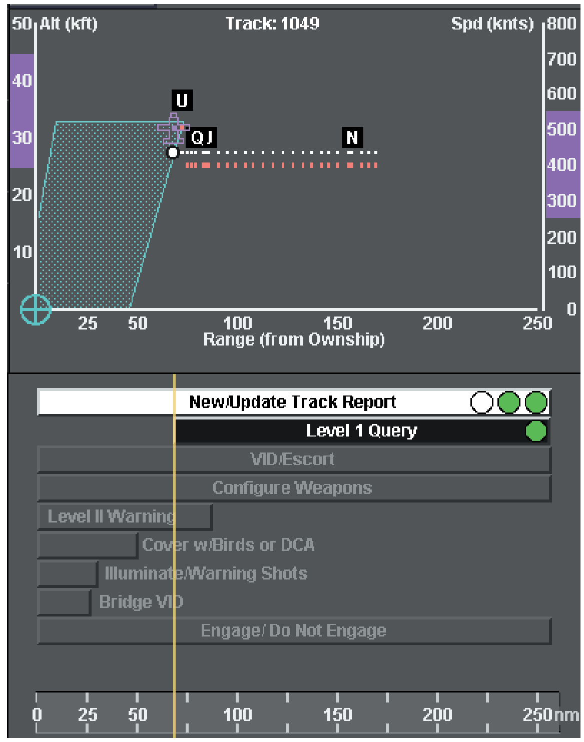

FIGURE 3. Track Profile (upper window) and Response Planner (lower window) displays. This example shows that a New Track report, two Update reports, and a Level 1 Query were previously completed. The track is progressing at a steady altitude (25 kft) and speed (450 knts). The tactical graphics show the weapons envelopes of ownship in teal, and, if applicable, unknown or suspect track possible weapon envelopes are shown in red.

Attention Management

The MMWS design considers the requirement to guide user attention through all phases of the task life cycle. These phases are (1) initiation, (2) orientation, (3) decision, (4) execution, (5) confirmation, and (6) transition. User attention must be directed across and within task activities. Figure 4 illustrates the benefits of consistent color-coding across windows, within a task type. Color-coding for ID illustrates

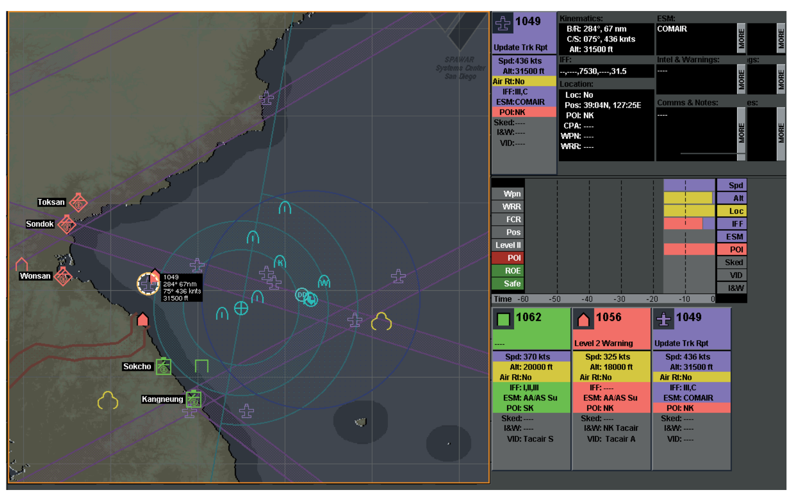

FIGURE 4. Consistent color-coding for ID and improved tactical graphics help to guide user attention and speed visual search tasks. Consistent color-coding across displays aids in information scanning and interpretation. The Track Profile (Figure 3), Amplifying Info, Basis of Assessment, Mini-Amp-Info, and Tactical Displays shown in this figure illustrate the common coding used throughout all windows.

evidence both for and against a given ID assessment. Uniform color represents higher ID certainty while a "rainbow" of color represents less certainty. At a glance, the user can see in each display if there is consistent or conflicting ID evidence, and can quickly assess where the conflicts exist. The Basis of Assessment display provides a history of the changes in ID basis; thus, the user can tell if the data elements are consistent over time or changing. This coding supports efficient visual scanning and task dwell-time optimization. Experts dwell on problem areas such as a "suspect" track with an inconsistent ID basis, and spend less time visually sampling tasks or tracks with consistent information.

Another requirement exists to guide user attention in an efficient manner through multiple tasks. Task detection may be unreliable when the system relies on human vigilance during multi-tasking, and often users are reluctant to drop a non-critical task when a higher priority task appears. There can be a reluctance to leave work unfinished. The MMWS task management system monitors for task-event triggers in the environment. Relative to today's systems, user workload to monitor and trigger tasks should be significantly reduced, allowing attention resources to be allocated for task execution, not task detection. Also, tasks may be categorized with respect to both time and mission urgency. Task management displays have been found to improve judgments about the effect of delays for subtasks and global tasks when problems were introduced into task progress [10]. Results indicated significant performance gains for task management assistance in selecting appropriate response strategies for mission- and time-critical tasks. Automation to support task prioritization of the highest level task improved user efficiency.

Recent usability testing results for the MMWS [11] indicate that visual depiction of time and display scrolling on the task manager were not beneficial during high workload periods. This result led to a revision of the MMWS design concept to allow more tasks to be depicted without scrolling, using visual separation of completed, current, and pending tasks.

Design Testing and Analysis

A critical part of the design and engineering process involves usability testing with fleet participants. Testing involves user hands-on interaction with design items to obtain measures and observations of user training and acceptance, and to identify design items that invoke confusion, error, or slow performance. The goal is to test a few subjects to identify repetitive or common problems across all participants. Significant usability testing has been used to mature the designs in this capability to their current status. Over 75 military and civilian participants were tested from 1997 to 2000 as part of the MMWS development program. Metrics vary in usability testing depending on the focus for the test. During MMWS development, versions 1.x through 5.x were subjected to quantitative measurement. Figure 5 shows the successive changes in question accuracy as scored by accuracy points over four Version 3.x design iterations. Such measures provide an indication of design improvement. Design

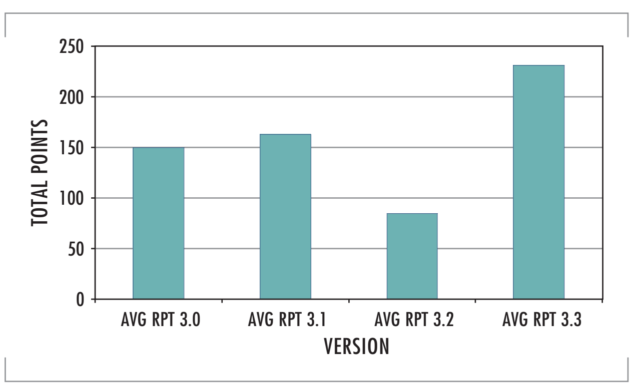

FIGURE 5. Points scored in testing over multiple design versions of MMWS.

comments and workload ratings provide indications of user preference and workload induced by the design and task scenario.

Team performance measurement is a critical design success criterion resulting in quantitative measures of the improvement of the MMWS capability in comparison to existing air defense decision support tools. A realistic air defense problem scenario was used for team performance assessment. The use of the scenario allowed specific comparison of teams using the MMWS Decision Support System (DSS) capability with Aegis teams tested with various Aegis software configurations. This allows a direct assessment of the MMWS DSS capability improvement vs. today's systems. The test was also designed to demonstrate a 50% crew reduction using eight operators in the Aegis team vs. four in the MMWS team. A test goal was to determine if workload and performance could be sustained with reduced crew sizes, such as those proposed for future ship teams. The scenario design was coordinated with Aegis Training and Readiness Command in Dahlgren, VA; subject experts at BCI, Dahlgren, VA; and scientists and engineers at SSC San Diego and Naval Air Warfare Center Training Systems Division (NAWCTSD), Orlando, FL. The scenario was engineered and set in a restrictive warfare environment to foster cognitive workload and decision-making under ambiguous circumstances. Fleet comments at the conclusion of test sessions indicated the scenario was as realistic as other operational test scenarios used in fleet training.

The test scenario contained low and high workload periods and a "coast period" was used in the middle portion of the scenario to allow for further data collection. In the second period, there were more tracks, increased ambiguity of information, and a higher threat situation. The operational parameters for the scenario were defined including:

1. Political Summary
2. Ownship Mission and Tasking
3. Air Tasking Order (ATO) and Carrier (CV) Flight Plan
4. Rules of Engagement (ROE) and Warning/Weapon Status
5. Operational Tasks (OPTASK) Link-ID
6. South Korean Military Tactical Air (TACAIR)
7. OPTASK Air Warfare Plan
8. Call-Signs
9. Operations Order (OPORDER), Warfighting Doctrine and Policy Guidance
10. Communications Assumptions and Plans
11. Location of Air Routes, Return-to-Force Routes, Air Fields and Stations

The scenario was conducted in Condition III steaming, with restrictive ROE and weapons posture for the battlegroup ranging from white/safe to red/tight. Measures included in this study were speed, timeliness, and accuracy (errors of omission or commission). As shown in Figure 6, multiple types of data were collected, including the following:

Timeliness and Accuracy. Collected by viewing video and audiotapes of team actions. Task times were also logged for the enhanced capability version of MMWS.

Efficiency and Workload Capacity. Workload ratings obtained by online scales. Proportion of low criticality tracks addressed by both teams.

Expert Opinion. Subject experts in a review team were assigned to an individual operator. They recorded subject responses to critical track events (25 identified) using the Shipboard Mobile Aid for Training and Evaluation (SHIPMATE) hand-held device.

Situation Awareness. Three probes were conducted during the low and high workload periods. A post-events questionnaire was used during the middle and final coast periods. Questions asked included the following: (1) What are your current tracks of interest? (2) What is your assessment of the intent of Track X? (3) What is your intent with respect to Track Y?

A post-events questionnaire addressed the top tracks of interest and an explanation of the interest. Performance-based inferences also were derived based on tactical response to events in the scenario. Subject-matter experts rated planning, prediction, and critical thinking. The same measures and probes were used for previous Aegis tests [12] and will allow for comparison and measurement of success in this project.

Test Result Highlights

Table 3 shows results indicative of the situation awareness improvement in teams tested using MMWS vs. Aegis crews using legacy equipment. The critical scenario event included a track that appears to be a COMAIR initially, but demonstrates several important kinematic (course, altitude, speed) and other ESM information changes that would warrant increased suspicion. Note in Table 3 that fewer Aegis crews queried or warned the track prior to it attacking the battlegroup, while all MMWS crews did so. The MMWS teams exhibited confidence and awareness in their response actions. With apparently less situation awareness and decision support, Aegis crews used last-second response methods when the air threat launched missiles, while MMWS crews were fully prepared and forewarned. Figure 7 shows that even with a reduced crew size of 50% for the MMWS teams vs. Aegis, the MMWS estimated workload was lower throughout the entire scenario periods tested. Thus, the benefits of the MMWS design included increased situation awareness and performance, with less workload induced on the operating team: a clear win-win situation with respect to performance and workload, therefore reducing mission performance risk.

FIGURE 6. MMWS designs were subjected to individual and team testing in realistic tactical operations.

TABLE 3. Responses of Aegis and MMWS to kinematic changes and ESM events with a critical scenario threat.

	Kinematics	Query/Warning	Engage ASM
Aegis Teams	1 of 8	2 of 8	7 of 8
MMWS V1	6 of 6	6 of 6	6 of 6
MMWS V2	2 of 2	2 of 2	2 of 2

CONCLUSIONS

The MMWS project investigated the design concept of explicitly creating and embedding mission tasks and their associated goals within the visual user interface, using visual priority cues and task progress summaries. The user was assisted throughout the entire task life cycle. Draft task products were prepared for user review, in contrast to the manual workload in visual search, discovery, and task product creation in today's systems. Test results for usability and team performance indicate that the design concepts in MMWS could be a key enabler for crew performance, enabling improved situation awareness and workload reduction. This may be particularly true in multi-tasking missions where workload is externally paced and attention must be distributed across multiple simultaneous tactical events. Task management appears to support work in command and control environments that involve a mixture of rule-, skill-, and knowledge-based tasks. Task management greatly facilitates real-time workload assessment, useful for adaptive automation and re-allocation of functions between team members [13]. Further team-performance research is needed in these complex naval task environments to determine best methods for task distribution and automation monitoring by humans working cooperatively with intelligent task management aids.

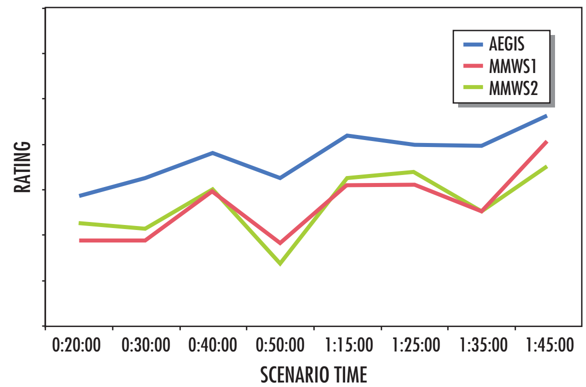

FIGURE 7. Workload levels across scenario periods for Aegis and MMWS as determined by subject-matter-expert ratings.

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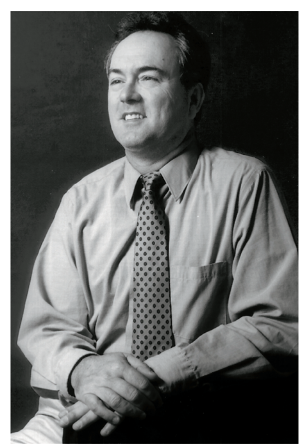

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